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FINAL REPORT

AGRO/ECONOMIC COMPARISONS OF DIVERSE CROPPING SEQUENCES IN THE SEMIARID PRAIRIELERS

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Agro/Economic Comparisons of Diverse Cropping Sequences in the Semiarid Prairie

Final Report
Submitted to Saskatchewan Agricultural Development Fund,
Saskatchewan Pulse Crop Development Board,
and Agriculture and Agri-Food Canada

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ABSTRACT

Growing crops in appropriate sequences will allow the crops to efficiently use resources to optimize yield and quality. This study was conducted at Swift Current (loam soil) and Stewart Valley (clay soil) from 1996 to 2000 to determine the best crop sequences for the semiarid regions. Pea yielded 2750 kg ha^{-1} (or 10% less than spring wheat), while pea used 3.5 cm less water than wheat; most of the unused water was located below the 60-cm soil depth. Chickpea yielded 1900 kg ha^{-1}, or 22% higher than mustard and 28% higher than lentil. Canola and wheat yields were 23 to 42% higher when grown on pea and lentil stubble than when grown on wheat stubble. Durum grown in the pulse-pulse-durum or pulse-canola-durum sequences yielded 2640 kg ha^{-1} with protein content 13.8%, while durum grown in the wheat-wheat-durum sequence yielded 2240 kg ha^{-1}, with protein content 11.8%. The remarkable rotational effects were attributed to increased soil water reserves and slow N release from the pulse residues.

EXECUTIVE SUMMARY

The experiment featured three pulses (desi chickpea, field pea, and lentil), one oilseed (oriental mustard), and one cereal (hard red spring wheat) grown as the first year crops on tilled fallow. In the following year (year 2), a common set of crops (wheat, an oilseed, and a pulse crop) were grown on the five previous crop stubbles; and in the 3rd year of the crop sequence, durum was uniformly grown on all 15 combinations of stubble treatments (i.e., 5 crop types from the 1st year x 3 crop types from the 2nd year). Each of the three-year crop sequences was repeated for three cycles during the 1996 to 2000 period. The experiment was conducted on a loam soil at Swift Current and on a clay soil at Stewart Valley, Saskatchewan.

Among the five first-year crops, wheat produced the highest grain yields ranging from 2700 to 3400 kg/ha, followed by pea with yields ranging from 2400 to 3100 kg/ha (or 10% less than spring wheat on average). Chickpea yields averaged 1900 kg/ha, or 22% higher than mustard and 28% higher than lentil. Chickpea produced high yields despite being plagued with Ascochyta blight in all three years at Swift Current, and despite heavy weed infestations in all 6 site-years. Only two post-emergent herbicides were registered for broadleaf weed control in chickpea, fewer than for any of the other crops.

Although pea produced 10% less yield than spring wheat, its water-use-efficiency was similar to that of spring wheat. Pea has a shallow rooting pattern with most rooting located in the top 60-cm soil depth. When averaged for the 6 site-years, pea used 3 to 4 cm less water than wheat; most of the unused water was located in the 60-120 cm soil depth. This amount of soil water reserve may account for 300 to 350 kg/ha of yield increase when spring wheat is grown on pea stubble in the following year. Lentil had a similar rooting pattern and ability to conserve soil water as pea; however, lentil generally produced lower grain yields. Unlike pea and lentil, most of the chickpea varieties currently grown in Canada are tap-rooted, which takes advantage of stored water from lower soil

depths, thus it conserving less soil water than pea or lentil, but similar amounts to mustard and wheat.

Post-harvest residual soil N levels were higher for the pulse crops, averaging 35 kg N ha^{-1} for pea and 27 kg N ha^{-1} for lentil and 20 kg N ha^{-1} for chickpea. Based on these residual soil N levels and N credits for pulse residues, we calculated fertilizer N equivalents for the second-year wheat and oilseed crops. Despite this equal soil available N and equal yield goal, the yield of spring wheat grown in the following year was significantly affected by previous crop type. The yield advantage of wheat ranged from 380 kg ha^{-1} (or 17% higher) when grown on mustard stubble to 670 kg ha^{-1} (or 30% higher) when grown on pea stubble (compared to wheat grown on wheat stubble). This trend was consistent across all site-years, except at Swift Current in 1997, when no yield advantage was observed. Wheat grown on wheat stubble averaged 65% of the yield of wheat grown on fallow, while wheat grown on pea and lentil stubble averaged 80 to 82% of fallow-wheat yields.

Among the five crop types studied, pea and lentil have conferred the largest rotational benefits to crops the following years, probably due to a combination of conserved soil water and soil residual N by these pulse crops. Wheat grown on pea or lentil stubble had the highest harvest index, suggesting that symbiotic N conserved in the soil by previous pulses are continuing to feed the growing wheat in the latter part of their life cycle. The rotational benefits of chickpea were similar to that of mustard, but were less than those observed for pea or lentil. Chickpea may be expected to perform relatively better on fallow than as a stubble recrop option. This may be important especially for kabuli chickpea where kernel size is paramount to receiving market price premiums.

Oilseed crops (mustard or canola) performed excellently when grown on pea and lentil stubble. On average, the yield of the oilseed was 23% higher when grown on lentil stubble and 42% higher on pea stubble, than when grown on wheat or mustard stubble. The great

yield advantages associated with the pulse stubble were likely due to a combination of conserved soil water and residual N below the 60-cm soil depth. Canola yields were the lowest on mustard stubble, partially due to early competition from a dense flush of volunteer mustard.

Results for pulse crops grown on pulse stubbles were mixed. In two out of six site-years (i.e., at both sites in 1997), lentil produced the highest grain yield when grown on pea stubble. In all three years, pea and lentil yielded higher when grown in each other's stubble than when grown on their own stubble. Lentil and pea share a common strain of rhizobial inoculant, and the crops showed excellent vigour when grown on each other's stubble, presumably due to a more timely nodulation by the soil resident-rhizobia which were introduced the previous year.

Other factors unrelated to nodulation were also causing differential yield responses. In 1998 and 1999 at both sites, pea produced the highest yield when grown on wheat stubble and the lowest yield when grown on its own stubble. The standing wheat stubble provided the pea seedlings with excellent surface soil moisture and a protective shelter in the early developmental stages. This protection to seedlings can be important in southwestern Saskatchewan where broadleaf crops are usually subject to wind stress in the early spring. Pea grown on its own stubble tended to yield the lowest, presumably due to carryover of soil-borne crop-specific pathogens. Further studies are needed to determine whether a mix of pulse crops can be grown back-to-back, to share soil residual symbiotic rhizobial benefits, and to assess how the back-to-back seeding of pulses would impact disease and weed infestations.

The response of durum to the previous crop type was significant. The previous two years of pulse crops or the pulse-oilseed, oilseed-pulse alternated crop sequences provided durum with the greatest yield benefits. On average, durum seeded in the pulse-pulse-durum crop sequence produced the highest grain yield (2660 kg ha^{-1}), followed by pulse-

canola-durum (2620 kg ha^{-1}) and mustard-pea-durum (2620 kg ha^{-1}). The durum seeded in the wheat-wheat-durum sequence produced the lowest grain yield (2240 kg ha^{-1}), which was 19% lower than from the pulse-pulse-durum sequence and 9% lower than from the fallow-wheat-durum sequence.

Protein of durum grown in the pulse-pulse-durum, pulse-oilseed-durum, or oilseed-pulse-durum sequence was >13.8% on average. Durum grown in the wheat-wheat-durum, and fallow-wheat-durum sequences had the lowest (11.8%) protein level. It appears that both grain yield and protein of the third-year durum were affected by a combination of the previous two years of crop arrangement. Durum protein levels were reduced sharply when grown on 2nd-year wheat stubble, averaging a remarkable 2 %-units drop as compared to durum grown on non-wheat stubble. These results suggest that slow N release from non-cereal crop residues late in crop growth stages markedly increases durum grain filling.

The timing of N release from decomposing pulse residues may have contributed to the observed large yield and protein benefits to the succeeding durum crop. In the long term, the inclusion of pulse crops in the crop sequence would significantly enhance the soil labile nitrogen pool and improve soil N availability for the N-loving crops such as cereals. Aside from the slow N release from pulse residues, other factors such as reduced disease and weed competition may have contributed to the huge rotational benefits. More detailed studies are needed to elucidate the impacts of the inclusion of pulse crops in cropping systems on changes in soil biodiversity, weed seedbank and spectra, disease, and overall soil quality.

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OVERALL BACKGROUND

The study was initiated in 1995 at the Semiarid Prairie Agricultural Research Centre (SPARC), Swift Current, with the financial support from Saskatchewan Pulse Crop Development Board. In 1996, a second site on a clay soil at Stewart Valley was started with the funding provided by Saskatchewan Agricultural Development Fund (ADF). The two sites and three years of study were completed in the 2000 growing season. According to the research contract with ADF, there was no requirement to conduct the 3rd-year durum re-cropping. However, SPARC decided to re-crop durum on the 15 different crop stubbles as the 3rd year crop, as means of determining the rotational effects of previous crop types on durum grain yield and quality. Remarkable responses of durum to the crop sequence has been found from this study. Thus, in this report to ADF, we have included the results of the third-year durum crop.

DESCRIPTION OF THE EXPERIMENT

1. Management for 1st year crops

Five crops were grown in a randomized, complete block design with three replicates at Swift Current (a loam soil) and Stewart Valley (a clay soil) in 1996, 1997, and 1998. Each year, *Laird* lentil seed was treated with *Crown* fungicide and planted at a rate of 140 viable seeds per m^2. *Grande* yellow pea seed was treated with *Apron FL* fungicide and planted at a rate of 80 viable seeds per m^2. *D*esi chickpea seed was treated with *Crown* + *Apron FL* fungicides and planted at a rate of 65 viable seeds per m^2. *Cutlass* Oriental mustard seed was treated with *Vitavax RS* pesticide and planted at a rate of 230 viable seeds per m^2, and finally *Katepwa* wheat, treated with *Vitavax Dual* fungicide, was planted at a rate of 250 viable seeds per m^2. All crops were planted on tilled fallow to ensure a full soil moisture profile. Mustard and wheat were fertilized such that total available N equalled 70 kg/ha (soil plus fertilizer N), according to soil tests and target yields. The three pulses received 20 to 33 kg of 11-51-0 /ha of product applied with the seed, with no additional N applied. Granular inoculant was applied to the pulse crops at 5 - 8 kg/ha. *Furadan Granular* was added to the mustard seed at a rate of 4.5 kg/ha.

In each year, a comprehensive herbicide program was used to ensure that all plots were maintained at a nearly weed-free condition, avoiding possible effects from weeds. The specific herbicides used for each crop differed slightly from year to year, depending on weed species and intensity. Prior to seeding, *Heritage 5G* herbicide was applied at 22 kg/ha to all plots except wheat, and the entire site was cultivated and harrow-packed. All crops were seeded into warm moist soil (daily max. soil temperature at 10-cm depth was between 9 and 11°C). *Sencor* herbicide at 0.12 L/ha was applied to the lentil plots; *Achieve* herbicide at 90 g/ha and *Buctril M* herbicide at 0.5 L/ha were applied to the wheat plots; and *MCPA Amine 500* herbicide at 0.25 L/ha was applied to pea. In June, *Decis* insecticide at 68 ml/ha was applied to mustard plots for flea beetle control. *Bravo* fungicide at 0.8 to 1.2 L/ha was applied to chickpea plots to control ascochyta blight

during late June and early July with a second application applied as needed. At early maturity, *Reglone Pro* desiccant at 0.9 L/ha was usually applied to lentil. Crops were harvested individually when they reached full maturity. In mid-September all plots recived burnoff treatment with *Roundup* and *2,4-D Amine 600* herbicides, and the plots were marked for the following year crops.

2 Management for the 2nd year crops (re-cropping)

A common set of crops (wheat, an oilseed, and a pulse) were re-cropped on the five different crop stubbles in each of 1997, 1998, and 1999, at Swift Current and Stewart Valley. Due to herbicide residue concerns with *Odyssey* herbicide applied in pea plots and *Lontrel* herbicide applied in the mustard plots in the previous year, the oilseed recrop was switched from *Cutlass* Oriental mustard to *Liberty-link 45A71* argentine canola, and the pulse recrop was switched from lentil to pea in the re-cropping years of 1998 and 1999. At both sites, the seeding rate for pea, wheat and canola was 85, 250 and 240 viable seeds per m^2, respectively. Pea seed was treated with *Apron FL* fungicide, wheat seed was treated with *Vitavax Dual* fungicide, and canola seed was treated with *Premiere Plus*.

The recropped mustard/canola and wheat were fertilized to have total available N at 70 kg/ha, based on previous fall soil test sampling. The N credit from the pulse stubble was taken into account in the fertilizer calculation. In this manner, canola and wheat grown on the pea stubble received an average of 20 kg N ha^{-1} less than canola and wheat grown on wheat stubble. Canola and wheat grown on the lentil and chickpea stubbles received 12 kg N ha^{-1} less than those grown on wheat stubble. Pea crop grown on wheat stubble received 7 kg N/ha to equilibrate available N with the pea grown on pea or lentil stubble. All plots received 17 kg P ha^{-1} placed with the seed.

In 1997 and 1999, soil moisture was adequate, and all 2nd -year crops were planted into a moist seedbed. In 1998, crops were planted into warm, dry soil (daily max. soil temp. at

10-cm depth was 16°C). The soil surface was dry in the top 5-cm and a decision was made to plant all crops at appropriate depths and wait for rain to moisten the seedbed. The seedbed continued to dry rapidly and rain was not received until 8 days after seeding. This caused a 2-week delay in the emergence of canola, and for wheat and pea grown in the non-wheat plots. The heavy residue cover from the 1997 wheat plots conserved sufficient moisture to facilitate germination of the recropped wheat and pea crops. For plots grown on mustard stubble, *Roundup* herbicide was applied at 0.6 L/ha prior to emergence in canola and pea plots, and *Buctril M* herbicide was applied at 0.5 L/ha on wheat plots. Late May, *MCPA Amine 500* herbicide was applied @ 0.25 L/ha on pea plots and *Buctril M* herbicide @ 0.50 L/ha to wheat plots. Crops were harvested individually when they reached full maturity. In mid-September, the entire site received a burnoff treatment of *Roundup* and *2,4-D Amine 600* herbicides at 0.6 L/ha each, and the plots were saved for the 3rd-year re-cropping.

3. **Management for the 3rd year crop – durum**

Kyle durum was uniformly seeded on the 15 combinations of stubbled fields in 1998, 1999, and 2000, at Swift Current and Stewart Valley. Seed was treated with *Vitavax Dual* fungicide at 3.6 ml per kg of seed, and was planted at the seeding rate of 250 viable seeds per m^2. According to soil test values for the previous year's crop type, 35 to 56 kg N/ha was applied in the mid-row band, along with 12 to 17 kg P/ha applied with the seed. *Roundup* herbicide was applied pre-emergent to all plots, and *Buctril M* herbicide at 0.46 L/ha was applied post-emergent for durum grown on mustard stubble to control volunteer mustard plants. *Achieve Extra Gold* herbicide was also applied at the recommended rate when needed.

4. **Weather Conditions**

Monthly precipitation during the growing season (May to August) was similar to the long-term normals in 1997 and 2000; it was much higher in 1999 and lower in 1998 than the 40-year mean. In 1998, El Nino produced the warmest April temperatures recorded at

Swift Current, which permitted seeding to get off to an early start. However, a rain-free period extending from late April to mid-May left many crop seeds stranded in dry soil. May and early June continued to be unusually warm and dry, which caused plants to develop under considerable drought stress. On June 16 the rains started, providing 12 cm of rain during the next 25 days, resulting in rapid plant growth and ideal conditions for foliar disease. Then as suddenly as it had begun, the rains quit and the crops were subjected to severe drought stress by late July. In contrast, in 1999, rainfall started in the early May which delayed some of the seeding work until late May. The amount of rainfall received during the 1999 growing season was far more than normals, resulting in high grain yields for all crops, although the moist environment caused mild to severe diseases, particularly Ascochyta blight in chickpea.

MAJOR FINDINGS

Chapter 1. Relative Agronomic Performance of Pulses, Oilseed, and Cereal Crops in the Semiarid Prairies (Tables 1 to 7)

Vegetative Growth

Stand establishment was successful for all crops in all six site-years (Table 1), except in 1997 at Stewart Valley where plant densities were lower than targeted for all crops, especially lentil (Table 2). Days to maturity differed by 8 days among the five crops (Table 1). Averaged across six site-years, desi chickpea required the longest period to mature (98 d), and pea the shortest (89 d). Days from flowering to maturity represents the reproductive period during which the maximum number of seeds are set and then grain dry matter starts being accumulated in the grains. Chickpea had the longest reproduction period (44 d) and pea had the shortest reproduction period (29 d). Large differences in harvest index (the ratio of seed yield to the total biomass yield) were found among the five crops, with chickpea and pea having the highest harvest index (0.40) and mustard the lowest (0.27). The high harvest index for pea and chickpea indicates that these crops have a high efficiency of partitioning photosynthetic materials into grains from the vegetative tissues.

Grain Yield

The grain yield of pea was generally similar to that of spring wheat in most site-years (Table 3); however, the yield of pea was lower than that of wheat on the clay soil at Stewart Valley where the seeding dates were later than desired for pea. Delayed seeding caused the pea crop to lose yield potential more rapidly than wheat (Miller et al. 1998; Gan et al. 2000). Despite the lower (10%) yield of pea than wheat at the Stewart Valley locations, water-use-efficiency (WUE) of pea was equal to that for wheat, indicating that

pea used less water to make its grain yield. Comparing among the different crops, chickpea showed a surprisingly strong yield potential by outyielding both lentil and mustard. Average seed yield of chickpea was 22% higher than that of mustard and 28% higher than that of lentil. Chickpea produced higher yields than lentil or mustard despite being plagued with ascochyta blight in all three years at Swift Current, and despite competing with moderate weed infestations in all 6 site-years. When this study began, there was no post-emergent herbicides were registered for use in chickpea.

Soil Water Use

Soil water use was calculated by measuring the amount of soil water at spring planting and in fall immediately after harvest. Soil cores were taken to a depth of 120 cm in each plot. These soil cores were divided into 0-15, 15-30, 30-60, 60-90, and 90-120 cm segments. Soil water was determined gravimetrically on each segment. Gravimetric water content was converted to volumetric units using measured bulk densities (1.26, 1.29, 1.39, 1.54, and 1.63 Mg m^{-3} for the five respective depths at Swift Current, and 1.33, 1.34, 1.44, 1.52, and 1.59 Mg m^{-3} for the five respective depths at Stewart Valley). Total amount of water was the sum of the water from the five soil depths. The soil water use pattern shows clearly that among the five crops, pea and lentil used less water from the 0-120 cm soil depth (Table 4). On average, pea used 29% less water than wheat, and lentil used 24% less water than wheat. Water use from the top 60-cm soil depth was similar for the five crop types. Pea and lentil have shallower rooting patterns so less water was extracted from below the 60-cm soil depth. Soil water conservation by pea and lentil also varied slightly with soil texture (Table 5). On the loam-textured soil at Swift Current, the average difference in water use between wheat and pea was 31 mm, and it was 46 mm on the clay-textured soil at Stewart Valley. For the 1998 Dryland Cropping Systems - "Harvesting Water" field day at SPARC, a trench-wall soil profile was created to expose the rooting systems of canola, pea and wheat. Visual observations of rooting patterns confirmed the shallow rooting habit of pea, with the majority of its root length appearing above the 60-cm soil depth. Quantifying this difference in rooting depth and

resultant soil water extraction, has been valuable when discussing extended crop rotations in the Brown soil zone. Soil water use pattern for chickpea was similar to mustard and spring wheat (Table 4), consistent with the results from our earlier small-plot investigations at Swift Current. Understanding the differences in rooting depth among the pulse crops is key information in designing extended crop rotations. Using this information, a strong case can be made for including pea and lentil in the rotation as recrops on wheat stubble, since soil water recharge in wheat stubble is often limited to 60-cm depth or less. A limited depth of available soil water handicaps a shallow-rooting crop less than it does to a deep-rooting crop. The residual water below the 60-cm soil depth increases the likelihood of a deeper-rooted recrop benefiting from the water conservation. This often results in pea and lentil replacing acreage that would have otherwise been fallowed. Unlike pea and lentil, chickpea is a deep tap-rooted crop, which takes advantage of stored water at deeper soil depths. Consequently, it may be expected to perform relatively better on fallow than as a stubble recrop (compared with pea and lentil). This may be especially important for kabuli chickpea where seed size is paramount to receiving high market price premiums.

Post-Harvest Soil Residual N

Soil cores, taken from 0-120 cm soil depth for water measurements were also used for soil nutrient determinations. When measured to a 60-cm soil depth, the pulse crops showed marginally higher post-harvest soil residual NO_3-N than wheat and mustard (Table 6). Pea had the highest post-harvest soil residual NO_3-N, followed by lentil and chickpea. When sampled to the 120-cm soil depth, the differences in residual NO_3-N became greater among the five crops. Area seeded to pea crop contained 35 kg ha^{-1} of residual soil NO_3-N, or 18 kg ha^{-1} more than that formed in wheat plots. Plots seeded to chickpea had less soil residual NO_3-N than the pea plots, but significantly higher than wheat or mustard plots. The patterns of residual soil N were consistent with crop rooting depths. These observations were similar across the three years and on both soil textures (Table 7).

In addition, we calculated N equivalence for the different types of crop stubble (Table 6), by summing the post-harvest soil residual N to a 60-cm depth and the N credits estimated from the seed yield of the pulse crops (0.5% of grain yield for pea and lentil, and 0.4% of grain yield for chickpea). The N equivalent information was used in fertilization management for the 2nd-year crops. For the oilseed and wheat 2nd-year crops, fertilizer N application was adjusted to provide an equal amount of soil available N, targeting an equal yield goal on all crop stubbles. In this manner, crops grown on the pea stubble received an average of 20 kg N ha^{-1} less than crops grown on wheat stubble. Similarly, crops grown on the lentil and chickpea stubble received 10-12 kg N ha^{-1} less than those grown on wheat stubble. This size of the N contribution from pulse stubble was larger than expected when compared to recent results from the Dark Brown soil zone at Scott, SK (Beckie and Brandt 1997). Possibly N contributions from the pulse crops, especially pea, were underestimated by not accounting for residual N below the 60-cm soil depth. This additional residual N below the 60-cm soil depth is consistent with the soil water extraction patterns and, together with conserved soil water, may explain the generally greater grain yields of cereals grown on pea stubble observed in trials conducted at Swift Current.

Table 1. Plant density, biomass production, and harvest index for alternative crops tested at Swift Current and Stewart Valley (1996 to 1998).

Crop	Plant density	Days to mature	[§] Days of reproduction	Biomass yield	Harvest index
	(plants/m^2)	(days)	(days)	(kg/ha)	--
Wheat (CWRS)	176 a	96 b	30 d	7920 a	0.38 a
Mustard (oriental)	124 b	90 d	43 b	5790 c	0.27 c
Pea (yellow)	55 d	89 e	29 e	6330 b	0.40 a
Lentil (Laird)	73 c	91 c	31 c	4320 c	0.34 b
Chickpea (desi)	52 d	98 a	44 a	4810 d	0.40 a
$LSD_{(0.05)}$	9.6	0.7	0.8	417	0.035

Values within a column followed by the same letter are not statistically different (P<0.05).

[§] Days of reproduction means days from flowering to maturity.

Table 2. Plant density for the 1[st]-year crops grown at Swift Current and Stewart Valley (1996 to 1998).

Crops	Swift Current			Stewart Valley		
	1996	1997	1998	1996	1997	1998
	plants / m^2					
Wheat (CWRS)	154 b	185 a	204 a	171 a	115 a	224 a
Mustard (oriental)	191 a	160 b	83 b	92 b	59 b	159 b
Lentil (Laird)	82 c	65 c	70 bc	71 c	41 c	108 c
Pea (yellow)	54 d	51 c	66 cd	49 d	35 c	74 d
Chickpea (desi)	56 d	49 c	54 d	42 d	37 c	75 d
$LSD_{(0.05)}$	17	16	14	13	13	14

Values within a column followed by the same letter are not statistically different (P<0.05).

Table 3. Mean grain yield of five different crops grown from 1996 to 1998 on a loam soil at Swift Current and on a clay soil at Stewart Valley.

Crop	Growing season			6 site-year	Soil type	
	1996	1997	1998	mean	loam	clay
	---------- kg ha^{-1} ----------					
Wheat (CWRS)	3328 a	2866 a	2768 b	2987 a	3042 a	2933 a
Pea (yellow)	2877 b	2390 b	3024 a	2700 b	3060 a	2198 b
Chickpea (Desi)	1706 c	1968 c	1978 c	1889 c	1907 b	1866 c
Mustard (Oriental)	1539 c	1299 d	1781 c	1540 d	1707 c	1373 d
Lentil (Laird)	1716 c	1212 d	1500 d	1477 d	1691 c	1262 d
$LSD_{(0.05)}$	254.5	164.6	199.6	134.7	169.9	185.2

Values within a column followed by the same letter are not statistically different ($P<0.05$).

Table 4. Soil water use at the different soil depths by the 1st-year crops grown at Swift Current and Stewart Valley (1996 to 1998).

Crop	Soil depth (cm)				% over wheat
	0 - 60	60 - 90	90 - 120	0 - 120	
	water use, mm				(%)
Wheat (CWRS)	77.2	37.3	19.8	134.4	0
Mustard (oriental)	77.0	30.5	21.3	128.8	-4
Chickpea (desi)	80.0	29.0	14.0	122.9	-9
Lentil (Laird)	74.7	19.6	7.6	101.9	-24
Pea (yellow)	72.6	16.8	5.8	95.3	-29
LSD (0.05)	5.1	3.8	3.6	7.1	--

Table 5. Soil water use (0 - 120 cm soil depth) by the 1st year crops grown on a loam soil at Swift Current and on a clay soil at Stewart Valley (1996 to 1998).

Crops	Loam soil				Clay soil			
	1996	1997	1998	Mean	1996	1997	1998	Mean
	water use, mm							
Wheat (CWRS)	119	170	112	**134**	142	130	127	**133**
Mustard (oriental)	119	175	112	**135**	127	117	124	**123**
Chickpea (desi)	112	155	112	**126**	130	127	107	**121**
Lentil (Laird)	102	152	99	**118**	99	76	86	**87**
Pea (yellow)	91	127	91	**103**	91	97	74	**87**
LSD (0.05)	15	15	15	**15**	18	20	25	**21**

Table 6. Post-harvest residual soil NO_3-N and calculated N equivalent for the five different crops grown from 1996 to 1998; the N equivalent was calculated as residual soil NO_3-N in the 60-cm soil depth plus N credits from pulse residues.

Crop	Soil residual NO_3-N in the soil depth (cm)		N Equivalent
	0 - 60	0 - 120	
	kg ha $^{-1}$		
Pea (yellow)	18.1 a	35.1 a	31.6 a
Lentil (Laird)	14.1 b	27.5 b	21.5 b
Chickpea (desi)	13.1 b	25.1 b	20.7 b
Mustard (oriental)	12.5 b	20.8 bc	12.5 c
Wheat (CWRS)	10.3 bc	17.4 c	10.3 c
$LSD_{(0.05)}$	3.8	6.9	--

Values within a column followed by the same letter are not significantly different ($P<0.05$)

Table 7. Calculated N equivalent (residual soil NO_3-N in the 0-60 cm soil depth plus N credits of pulse residues) for the five 1st-year crops grown at Swift Current and Stewart Valley (1996 to 1998).

Crops	Swift Current			Stewart Valley		
	1996	1997	1998	1996	1997	1998
	kg ha^{-1}					
Pea (yellow)	25.8	29.1	28.0	41.4	30.2	32.5
Lentil (laird)	13.4	20.2	20.2	29.1	21.3	20.2
Chickpea (desi)	12.3	23.5	14.6	26.9	26.9	20.2
Mustard (oriental)	7.8	11.2	6.7	13.4	22.4	14.6
Wheat (CWRS)	7.8	9.0	6.7	13.4	12.3	13.4
$LSD_{(0.05)}$	3.4	3.4	2.2	4.5	5.6	4.5

Chapter 2. Boosting Wheat Grain Yield by Growing Wheat on Crop Stubbles Other Than Wheat (Tables 9 to 16)

In recent years, many producers in the Brown and Dark Brown soil zones have been diversifying their cropping systems by including non-cereal crops in the rotation. The inclusion of those alternative crops provides producers with options to grow cereal crops on different types of stubble. Previous research has shown that cereal crops perform better on one type of stubble than on another type. Therefore, the part of this crop sequence study examined the impact of different types of stubble on wheat grain yield and quality.

Wheat Growth and Development

Plant densities for hard red spring wheat were generally optimal in all site-years and were not affected by the previous crop type (Table 9); however, in 1997 at Swift Current, the plant density of wheat grown on its own stubble was significantly lower (but within the desired range) than wheat grown on the other types of stubble. The density reduction was largely caused by excessive wheat residue which caused some difficulties with seed placement. Days to maturity ranged from 82 to111 days, depending on the year, and the differences among years were greater than the differences among stubble types (Table 10). In 1998, dry weather conditions during the early grain filling stage substantially advanced wheat grain maturity. In 1999, however, the moist growing conditions during the entire growing season delayed wheat maturity at both sites. Within a single growing season, wheat grown on pea stubble usually matured 1 to 2 days later than wheat grown on its own stubble. We took biomass yields at flowering stage by sampling 1-m^2 of plants in each plot to determine if differences were present in the vegetative growth of wheat on the different stubble types (Table 11). In most site-years, the previous crop type did not have an impact on wheat vegetative dry matter production, except in 1997 at Stewart Valley where wheat grown on pea and lentil stubble produced

the highest biomass yields, and wheat grown on its own stubble produced the lowest.

Wheat Grain Yield

Averaged across six site-years, wheat tended to produce greater yields when grown on other stubble types than when grown on its own stubble (Table 12). The yield advantage ranged from 380 kg ha^{-1} (or 17% higher) on mustard stubble to 670 kg ha^{-1} (or 30% higher) on pea stubble compared wheat grown on wheat stubble. This trend was consistent across all site-years, except one (Swift Current 1997) where yield advantage from pulse stubbles did not shown up. Compared to wheat grown on summer-fallow (as a check), wheat grown on its own stubble yielded 65% of fallow-wheat yields, and wheat grown on pea and lentil stubble yielded 80 to 82% of fallow-wheat yields. Among the five stubble types, pea and lentil generally conferred the largest rotational benefits to the subsequent wheat crop, probably due to a combination of higher soil water and residual N below the 60-cm soil depth found in the pulse plots. The differences in wheat grain yield among different stubble types were largely due to corresponding differences in the harvest index, since none or a little difference in dry matter production at flowering was detectable (Table 11). This may indicate an increase in N uptake at a later stage when wheat was grown on pea or lentil stubble, suggesting that residual symbiotic N generated by the pulses was still available for the wheat plants to take up during the grain filling period. The rotational benefits of chickpea were very similar to that of mustard, and were less than those observed with pea or lentil stubble.

There were significant year x site interactions for the yield of wheat grown on different stubble types. In 1997 at Swift Current, there were no detectable yield differences among the five crop stubbles (Table 12). However, in the same year on the clay soil at Stewart Valley, wheat produced 1260 kg ha^{-1} less (or 50% lower) yields when grown on its own stubble than when grown on any of the other stubble types. Spring soil conditions were nearly saturated on the clay soil, which was ideal for development of soil-borne cereal pathogens that attack the root system. It is likely that the improved performance of wheat

grown on the non-cereal stubbles in this site-year was related to a disease break. However, we did not measure the disease severity or incidence in the study. Comparing among the five non-cereal crop stubbles, pulse stubble resulted in 300 to 500 kg ha^{-1} higher wheat yields than when wheat was grown on mustard stubble. Among the three pulses tested, pea provided the largest yield advantages to wheat, followed by lentil, while chickpea provided the least benefit.

In 1998 at Swift Current, dry seedbed conditions hampered emergence in all low-residue stubbles (i.e. oilseed and pulse stubbles), resulting in a 2-week delay in wheat emergence. Wheat grown on its own stubble emerged earlier and was visually superior in the early development stages due to the better seedbed moisture, yet the final grain yield of wheat grown on its own stubble tended to be the lowest, measuring 200 to 600 kg ha^{-1} less than wheat grown on pea stubble (Table 12). It is possible that the delayed development of wheat grown on the non-cereal stubbles matched better to the intense, late-arriving rainfall pattern in that particular site-year plus the slow release of symbiotic N conserved in the soil by the previous pulses. At Stewart Valley in 1998 an unusual response occurred whereby wheat yields were significantly higher on pea stubble, equal on lentil, mustard and wheat stubbles, and significantly lower on chickpea stubble. A severe weed infestation occurred at Stewart Valley in the previous chickpea crop, which was not successfully controlled. The presence of broadleaf weeds caused a negative rotational effect in the wheat field the following year, despite early and excellent weed control in the wheat crop. This weed interference with the rotational benefits may merit further attention in the future cropping systems research.

Wheat Grain Quality

Kernel weight, one of the important grading factors for cereal grains, was measured for wheat grown on different stubble types (Table 13). Significant impacts of previous crop type on kernel weight were detected in 1998; wheat grown on pea and lentil stubble had the highest kernel weight, and wheat grown on its own stubble the lowest.

The drier than normal growing conditions at grain filling in 1998 at Swift Current resulted in low overall kernel weight, but differences among stubble types were still evident. In 1997 and 1999, however, there were no differences in wheat kernel weight among the five stubble types. These results indicate that the rotational benefits may be greater for the succeeding crops under more stressed conditions than under normal conditions.

Averaged over site-years, grain protein content (Table 14) was the highest for wheat grown on chickpea and lentil stubble (13.1%), followed by wheat grown on mustard and pea stubble (12.6%). Wheat grown on its own stubble had the lowest protein content (12.1%). This trend was consistent across the three years and the two sites, although the differences among stubble types were somewhat less at Stewart Valley than at Swift Current.

Soil Water Conservation and Water Use Efficiency in Wheat

Soil available water (to 120 cm soil depth) was assumed to be total volumetric water minus the lower limits of 154 mm for the loam soil at Swift Current, and minus the lower limits of 325 mm for the clay soil at Stewart Valley (Campbell et al. 1997). On both the loam and clay soils, soil available water at spring planting was the highest on lentil and pea stubble, and the lowest on mustard stubble (Table 15). This was expected because pea and lentil stubble had the most water in the soil profile (Table 16). Soil available water at planting was equally low on wheat, mustard, and chickpea stubble, particularly on the clay soil. As expected, soil available water at the spring planting was the greatest on fallow regardless of soil texture.

Crop water use was taken as the available soil water in spring minus the available soil water immediately after harvest plus precipitation between the two sampling times. Water-use-efficiency (WUE) was calculated as grain yield produced with per unit of water used (kg mm^{-1}). Water use efficiency tended to be the lowest for wheat grown on

its own stubble (Table 16), and the highest for wheat grown on pea and lentil stubble, which is consistent with the yield patterns (Table 14). Significant year x site interactions were observed for wheat WUE. In 1997 at Swift Current, the low WUE of wheat grown on pea stubble indicates that the subsequent wheat crop was ineffective in using the conserved water to make additional grain yield, in sharp contrast with both sites in 1998 and 1999. In 1997 and 1999 at Stewart Valley, WUE of wheat grown on chickpea stubble was high, due to the fact that the yield of wheat grown on chickpea stubble was equal to the yield of wheat grown on pea and lentil stubble, but the former had much less available soil water.

Table 9. Plant density of hard red spring wheat grown on five different stubbles at Swift Current (SC) and Stewart Valley (SV), from 1997 to 1999.

Crop stubble	1997		1998		1999		Mean
	SC	SV	SC	SV	SC	SV	
	plants/m^2						
Wheat	171	180	179	180	142	124	163
Pea	201	163	190	166	144	123	165
Chickpea	196	171	161	188	151	135	167
Lentil	211	163	168	182	139	141	167
Mustard	222	158	169	192	131	134	168
Lsd (0.05)	30.4	NS	NS	NS	NS	NS	NS

NS, no significant difference among the five crop stubbles at P<0.05.

Table 10. Days to maturity for hard red spring wheat grown on five different stubbles at Swift Current and Stewart Valley (1997 to 1999).

Crop stubble	Swift Current			Stewart Valley			Mean
	1997	1998	1999	1997	1998	1999	
	days						
Wheat	96	92	111	90	82	109	97
Mustard	93	92	109	92	88	109	97
Chickpea	96	94	109	93	87	107	97
Lentil	93	94	110	94	89	107	98
Pea	96	95	111	94	89	110	99
Lsd (0.05)	2.3	1.4	NS	1	2.7	NS	NS

NS, no significant difference among the five crop stubbles at P<0.05.

Table 11. Biomass at anthesis for hard red spring wheat grown on five different stubble types at Swift Current and Stewart Valley (1997 to 1999).

Crop stubble	Swift Current			Stewart Valley			Mean
	1997	1998	1999	1997	1998	1999	
	kg ha^{-1}						
Wheat	773	463	707	661	631	683	653
Mustard	694	482	799	853	529	834	699
Chickpea	838	513	778	850	514	793	714
Lentil	749	435	792	913	519	901	718
Pea	777	445	755	975	568	888	735
Lsd (0.05)	NS	NS	NS	180.4	NS	NS	NS

NS, no significant difference among the five crop stubbles at P<0.05.

Table 12. Grain yield for hard red spring wheat grown on five different stubbles at Swift Current and Stewart Valley (1997 to 1999).

Crop stubble	Swift Current			Stewart Valley			Mean	% overwheat
	1997	1998	1999	1997	1998	1999		
	kg ha^{-1}							
Wheat	2645	1335	2651	2538	1940	2176	**2214**	**0**
Mustard	2791	1642	3105	3496	1853	2704	**2598**	**17**
Chickpea	2723	1498	3145	3940	1670	3610	**2764**	**25**
Lentil	2642	1582	3394	3950	2147	3482	**2866**	**29**
Pea	2713	1967	3377	3837	2194	3222	**2885**	**30**
Fallow check †	3176	3077	3579	4203	2606	3499	**3357**	**52**
Lsd (0.05)	NS	NS	282.2	544.6	312	504.6	537.6	--

NS, no significant difference among the five crop stubbles at P<0.05.

†Wheat was grown in replicated, but non-randomized fallow plots. These data were not included in the statistical analyses but are provided here for comparison purposes.

Table 13. Kernel weight of hard red spring wheat grown on five different stubbles at Swift Current and Stewart Valley (1997 to 1999).

Crop stubble	Swift Current			Stewart Valley			Mean
	1997	1998	1999	1997	1998	1999	
	mg seed $^{-1}$						
Wheat	29.3	16.7	28.8	31.3	25.8	30.6	27.1
Mustard	28.3	19.7	29.7	30.4	27.2	32.0	27.9
Chickpea	28.9	19.7	30.7	30.5	24.0	34.4	28.0
Lentil	29.1	21.9	31.0	30.8	27.0	35.4	29.2
Pea	29.5	24.0	30.7	31.0	27.6	34.2	29.5
Fallow check †	29.6	27.2	31.5	.	30.5	34.8	30.7
Lsd (0.05)	NS	2.5	NS	NS	1.3	NS	1.1

NS, no significant difference among the five crop stubbles at P<0.05.

†Wheat was grown in replicated, but non-randomized fallow plots. These data were not included in the statistical analyses but are provided here for comparison purposes.

Table 14. Grain Protein Content of hard red spring wheat grown on five different stubbles at Swift Current and Stewart Valley (1997 to 1999).

Crop stubble	Swift Current			Stewart Valley			Mean
	1997	1998	1999	1997	1998	1999	
	%						
Chickpea	11.8	15.8	11.5	11.1	17.5	11.0	13.1 a
Lentil	12.3	15.3	11.1	10.9	16.8	12.0	13.1 a
Mustard	10.7	15.5	11.3	11	16.8	11.1	12.7 b
Pea	11.5	14.6	11.1	10.5	15.9	11.3	12.5 b
Wheat	10.2	13.3	10.7	10.9	16.5	11.2	12.1 c
Fallow check	12.2	12.5	11.4	11.3	14.9	12.9	12.5

Means followed by a different letter in the same column are significantly different at the probability of 95%. † Wheat was grown in replicated, but non-randomized fallow plots. These data were not included in the statistical analyses but are provided here for comparison purposes.

Table 15. Soil Available Water at planting in the following spring, measured on different stubbles on a loam soil at Swift Current and a clay soil at Stewart Valley (1997 to 1999).

Crop stubble	Loam				Clay			
	1997	1998	1999	% over wht stubble	1997	1998	1999	% over wht stubble
	mm			(%)	mm			(%)
Wheat	83	35	66	0	186	178	70	0
Mustard	75	37	30	-23	203	186	46	0
Chickpea	70	52	50	-6	192	165	87	2
Lentil	102	56	56	17	201	193	67	6
Pea	96	55	41	5	220	196	60	10
Fallow check †	105	107	70	54	236	213	125	32

NS, no significant difference among the five crop stubbles at $P<0.05$.

†Wheat also was grown in replicated, but non-randomized fallow plots. These data were not included in the statistical analyses but are provided here for comparison purposes.

Table 16. Water Use Efficiency of hard red spring wheat grown on five different stubbles at Swift Current (SC) and Stewart Valley (SV), from 1997 to 1999.

Crop stubble	Swift Current			Stewart Valley			Mean	% over wht stubble
	1997	1998	1999	1997	1998	1999		
	kg mm^{-1}							
Wheat	8.4	6.1	7.7	9.8	7.1	7.8	7.8	0
Mustard	8.6	6.7	9.2	12.4	6.7	10.1	9.0	15
Lentil	8.1	6.4	9.3	13.8	7.5	10.9	9.3	20
Pea	7.6	8.0	9.2	12.7	7.8	12.9	9.7	25
Chickpea	8.8	6.4	8.6	15.2	7.5	12.1	9.8	25
Fallow check †	9.2	10.7	9.5	13.1	7.8	11.6	10.3	32
Lsd (0.05)	NS	NS	1.2	2.5	NS	NS	1.8	--

NS, no significant difference among the five crop stubbles at $P<0.05$.

†Wheat also was grown on replicated, non-randomized fallow check. These data were not included in the statistical analyses but are provided here for comparison purposes.

Chapter 3. Impacts of Previous Crop Type on Seed Yield and Quality of Oilseed Crops (Canola or Mustard) in the Brown Soil Zone (Tables 17 to 21)

In 1997, at each of the two sites (Swift Current, and Stewart Valley), oriental mustard was re-cropped on five different stubble types (i.e., field pea, lentil, chickpea, mustard, and spring wheat). In 1998 and 1999, argentine canola (instead of the mustard) was re-cropped on the five stubbles. Fertilizers are applied to the re-cropped oilseed crops, to ensure that the total available N was equal to 65 to 70 kg N ha^{-1}, based on fall soil tests. Nitrogen credits from previous pulses were accounted for in the fertilizer requirement calculation. Each year, treatments were compared in a replicate, randomized complete block design.

Establishment and Vegetative Growth

Plant densities for the oilseeds were generally within the optimal range (50 -150 plants m^{-2}), with the differences being greater among site-years than among treatments within a single site-year (Table 17). In 1998 at Swift Current, dry seedbed conditions delayed seed germination and seedling emergence, resulting in an overall low plant density. The plant stand of canola grown on mustard stubble was significantly lower than canola grown on any other stubble. When grown on mustard stubble, canola establishment was reduced mainly due to early competition from volunteer mustard seedlings. In all other site-year, canola plant density was not significantly affected by the previous crop. However, there was a trend that canola grown on the non-cereal stubble had poorer emergence than canola grown on wheat stubble. This was attributed to the low level of soil surface residues on the non-cereal stubble which caused surface crusting affecting emergence.

Averaged across the site-years, days to maturity for canola and mustard ranged from 82 to 106 days (Table 18), with the differences being small among stubble types. In general,

canola grown on wheat stubble required 1 to 4 days less time to maturity than canola grown on pea or lentil stubble. In most cases, this had no effect on final seed yield. Biomass yields of the oilseed crops were determined by sampling 1-m^2 of plants in each plot at the flowering stage, to examine the impact of stubble type on canola vegetative growth (Table 19). In 1997 and 1999 at both sites, no differences in vegetative biomass were detected among stubble types. In 1998, a dry year, the previous crop type had a significant impact on canola vegetative dry matter production. At both sites, canola grown on pea stubble produced the highest biomass at anthesis, while canola grown on the other stubble had mixed results.

Seed Yield of Canola/Mustard

The yields of oilseed crops were highest when grown on pea and lentil stubble (Table 20). On average, yields were 23% higher on lentil stubble and 42% higher on pea stubble, than when grown on wheat or mustard stubble. The yield advantage associated with pulse stubble was likely due to a combination of higher conserved soil water and residual N below the 60-cm soil depth. Harvest index values (i.e., the ratio of seed to total biomass at maturity) were highest for oilseeds grown on pea and lentil stubble, suggesting that symbiotic N conserved in the soil by previous pulses plus conserved soil water are continuing to feed the growing oilseed crop at the late growth stages. Chickpea stubble did not provide equivalent benefits to the subsequent canola crop as did pea and lentil. The chickpea stubble resulted in only 5% higher canola yield than when grown on wheat or mustard stubble. Chickpea produced the least amount of residue of all crops, causing a drier soil surface at planting time. Canola yields were lowest on mustard or wheat stubble, largely due to early competition from a dense flush of volunteer mustard.

There were significant year x site interactions for canola yields. In 1997 and 1999 at Swift Current there were no significant differences among the five stubble types (Table 20); however, in all three years on the clay soil at Stewart Valley the oilseeds yielded the highest on pea and lentil stubble (78% higher than when grown on wheat stubble in 1997, and 56%

higher in 1999). The low yield of oilseed grown on wheat stubble at Stewart Valley was partly due to fertilizer N being immobilized by the heavy wheat residues or wetter soil conditions under wheat residue causing poor aeration and possibly N loss from denitrification.

In 1998 at Stewart Valley, the yield response of canola was inconsistent. Canola yield was clearly the highest on pea stubble, yielding 3- to 5-fold higher than canola grown on any other stubble type. We can offer no reasonable explanation for this effect. In this rather dry yield, canola yields were unacceptably low on all stubble types except on pea stubble. A late flush of grasshoppers caused severe crop damage at this site. Although there is no reason to expect damage levels to be less on one type of stubble versus another, more vigorous growth during early development stages may have helped reduce the yield loss when canola was grown on pea stubble as indicated by the high biomass at anthesis (Table 19). Further experiments are needed to elucidate how early plant growth and development would affect the ability of canola to tolerate or reduce insect damage in the latter phases of its life cycle.

Oil Content of Oilseed Crops

Seed oil content of canola/mustard tested in the study ranged from 41% to 53%, and varied greatly from year to year. Previous stubble type had no significant impact on oil content (data not presented). It appeared that the rotational effects were largely expressed in the yield of grain, not in the quality or oil content of the grain.

Soil Available Water at Spring Planting

We measured several soil variables on the various stubble fields to understand why canola crops do better on pea and lentil stubble than on other stubble. We found that there were significant differences among stubble types in the amount of water left in the soil profile at the time of spring planting (Table 15). Pea and lentil stubble had 10% more soil water reserves in the 120-cm soil depth than did wheat stubble. The available spring soil

water in chickpea stubble was less than those in pea or lentil stubble, but was equivalent to water in wheat stubble. Mustard stubble had the least available water among the five stubble types. In the previous growing season, mustard and wheat used the same amount of water (data not presented). The lower soil water reserves at planting in mustard stubble than wheat stubble was probably due to differences in snow trapping during the winter months, with snow retention being higher for wheat than for mustard stubble.

Canola Water Use Efficiency

Water-use-efficiency for canola or mustard tended to be highest when grown on pea and lentil stubble (Table 21.). This suggests that the positive yield responses of these two stubble types were affected by factors in addition to soil available water, most likely increased soil available N. In all the three years at Stewart Valley, the high WUE of the oilseed grown on lentil and pea stubble indicates that the rotational benefit provided by the pulse crops included factors in addition to increased soil available water. Conserved N below the 60-cm soil depth partly explains this increased WUE. At Swift Current in 1998 and 1999, a similar explanation accounts for the increased WUE for canola grown on lentil and pea stubble. The low WUE of canola grown on mustard stubble was due to an inadequate plant density for canola and to an early season flush of volunteer mustard. At Stewart Valley in 1998, it is interesting to note that WUE for canola grown on pea stubble was similar to other site-years, while the WUE values for canola grown on all other stubble types were much lower than expected. We can offer no reasonable explanation for this occurrence, but noted that grasshopper damage was less obvious in crops grown on pea stubble.

Table 17. Plant density of canola/mustard grown on five different stubbles at Swift Current (SC) and Stewart Valley (SV), from 1997 to 1999.

Crop stubble	1997		1998		1999		Mean
	SC	SV	SC	SV	SC	SV	
	-- Oriental mustard --		---------- Argentine canola ----------				
	---------- plants/m^2 ----------						
Mustard	165	115	30	104	102	119	106
Lentil	136	106	52	112	134	145	114
Pea	142	117	58	132	120	121	115
Wheat	137	100	64	126	148	122	116
Chickpea	131	104	53	148	169	104	118
Lsd (0.05)	NS	NS	14.6	NS	NS	NS	NS

NS, no significant difference among the five crop stubbles at P<0.05.

Table 18. Days to maturity for mustard/canola grown on five different stubbles at Swift Current (SC) and Stewart Valley (SV), from 1997 to 1999.

Crop stubble	1997		1998		1999		Mean
	SC	SV	SC	SV	SC	SV	
	-- Oriental mustard --		---------- Argentine canola ----------				
	---------- days ----------						
Wheat	86	83	96	83	106	96	92
Chickpea	88	84	97	82	105	97	92
Mustard	86	84	97	88	105	97	93
Lentil	87	85	97	84	106	98	93
Pea	87	88	98	88	106	98	94
Lsd (0.05)	NS	NS	0.91	1.66	0.72	NS	NS

NS, no significant difference among the five crop stubbles at P<0.05.

Table 19. Dry matter yield for mustard/canola grown on five different stubbles at Swift Current (SC) and Stewart Valley (SV), from 1997 to 1999.

Crop stubble	1997		1998		1999		Mean
	SC	SV	SC	SV	SC	SV	
	-- Oriental mustard --		---------- Argentine canola ----------				
	---------- days ----------						
Wheat	508	494	416	194	721	581	486
Chickpea	498	484	526	273	628	641	508
Mustard	551	481	374	495	662	500	510
Lentil	539	575	444	349	706	677	548
Pea	477	599	578	718	729	702	634
Lsd (0.05)	NS	NS	92.7	193.3	NS	NS	101.2

NS, no significant difference among the five crop stubbles at P<0.05.

Table 20. Grain yield for mustard/canola grown on five different stubbles at Swift Current (SC) and Stewart Valley (SV), from 1997 to 1999.

Crop stubble	1997		1998		1999		Mean	% over
	SC	SV	SC	SV	SC	SV		wheat stub.
	-- Oriental mustard --		---------- Argentine canola ----------					
	---------- days ----------							
Wheat	1199	1035	848	139	1768	1341	1055	0
Mustard	1310	1395	565	556	1586	953	1061	1
Chickpea	1101	1440	939	73	1626	1484	1110	5
Lentil	1233	1824	1032	253	1679	1737	1293	23
Pea	1196	1893	1140	1038	1781	1908	1493	42
Lsd (0.05)	NS	333.6	192.6	78.2	NS	340.5	357.4	--

NS, no significant difference among the five crop stubbles at P<0.05.

Table 21. Water Use Efficiency for mustard/canola grown on five different stubbles at Swift Current (SC) and Stewart Valley (SV), from 1997 to 1999.

Crop stubble	1997		1998		1999		Mean	% over wheat stub.
	SC	SV	SC	SV	SC	SV		
	-- Oriental mustard --		---------- Argentine canola ----------					
	---------- kg mm^{-1} ----------							
Wheat	3.7	4.8	3.6	0.5	5.0	6.5	4.0	4
Mustard	4.0	5.6	2.3	1.9	4.9	4.5	3.9	0
Chickpea	3.4	5.4	3.6	0.3	5.1	7.1	4.1	7
Lentil	3.6	7.2	4.0	0.8	5.3	7.6	4.7	22
Pea	3.8	6.3	4.4	3.7	5.7	7.1	5.2	34
Lsd (0.05)	NS	NS	0.58	0.28	NS	NS	0.4	--

NS, no significant difference among the five crop stubbles at $P<0.05$.

Chapter 4 Pulse Crops Perform Best When Seeded on Wheat Stubble in the Brown Soil Zone (Tables 22 to 28)

The benefits of diversified cropping systems in the Brown and Dark Brown soil zones are becoming widely recognized. In recent years, many alternative crops such as canola, mustard, pea, chickpea, and lentils have been shown to perform well in reduced tillage systems. Since different stubble types provide different levels of seedbed moisture and soil residual nutrients, it is essential to select crops that fit best on stubble conditions so as to maximize grain yield and profits. In 1997 at each of the two sites (Swift Current, and Stewart Valley), laird lentil was re-cropped on five different stubble types (i.e., field pea, lentil, chickpea, mustard, and spring wheat). In 1998 and 1999, dry pea was re-cropped on the five stubble types at both sites. All plots received 25 - 35 kg ha^{-1} of 11-51-0 fertilizer and 8 kg ha^{-1} of rhizobial inoculant (granular) placed with the seed.

Pulse Establishment and Growth

Overall, the plant densities of lentil or pea were in the acceptable level, ranging from 55 to 75 plants m^{-2} (Table 22). There were no significant differences in plant establishment among the five stubble types, although the mean plant density for lentil grown on mustard stubble in 1997 was slightly lower than for lentil grown on other stubble types. Days to mature for the pulse crops averaged 81 to 105 days (Table 23). Generally there were no significant differences among the five stubble types in 1997 and 1999 at either sites, while in 1998 pea grown on pea or lentil stubble delayed maturity by 2 days (compared to being grown on wheat or mustard stubble). Soil residual N conserved by the previous pulses might have contributed to the vigorous growth of the successive pulses, which caused a delay in maturity. Biomass of lentil, measured at anthesis, did not differ among the five stubble types (Table 24), but biomass of pea grown on pea stubble were significantly lower than when pea was grown on other stubble types in four site-years,

except 1998 at Stewart Valley where pea grown on chickpea stubble produced the lowest biomass.

Pulse Grain Yields

In 1997 at both sites, lentil produced the highest grain yield when grown on pea stubble and the lowest yield when grown on wheat or chickpea stubble (Table 25). In 1998 and 1999 at both sites, pea produced the highest yields when grown on wheat stubble and the lowest when grown on its own stubble. The exception was in 1998 at Stewart Valley where pea grown on chickpea stubble had the lowest seed yield, largely due to a heavy weed intestation. It is interesting to note that there was a general trend that pea or lentil yielded higher when grown in each other's stubble than when grown on their own stubble. Lentil and pea share a common strain of rhizobial inoculant and these crops have shown excellent vigor when grown on each other's stubble, presumably due to a more timely nodulation by the soil resident-rhizobia which were introduced to the plots the previous year. With the early drought stress in 1998, this effect was visually striking. Although this rhizobial effect would also be present when pulses were seeded on their own stubble, there was a yield depressing effect of seeding pulses on their own stubble. Further studies are needed to elucidate the effects of pulse crops seeded back-to-back or in a mixed fashion.

Pulse Grain Quality

Grain protein content of pulses was strongly affected by previous crop type (Table 26). In all three years at both sites, grain protein concentration was markedly higher (1 to 2% units) for lentil or pea grown on pea and lentil stubble than on other stubble types. In 1999 at Swift Current, the difference was a remarkable 6 %-units. Significant site and year interactions have occurred. The largest difference in protein yield was for pea grown on pea or lentil stubble in 1999 at Swift Current. It appears that the N status of a pulse crop varies significantly, which may be important in the calculation of pulse N credits for the succeeding crops. These results provide strong evidence that soil-resident rhizobia have a large effect on the nutrition status of a pulse crop. Although commercial rhizobial

inoculants are effective in producing nodulation in soils that have never grown a particular pulse crop, it is widely known that there is usually a lag-time coinciding with the late vegetative growth stage where pulse crops temporarily appear N deficient. This temporary deficiency normally does not occur where soil-resident rhizobia are present.

Kernel weight for pea differed little among stubble types (Table 27), with the exception of 1998 at Stewart Valley where kernel weights for pea grown on lentil or pea stubble were 8% higher than that from other stubble types, presumably also related to the soil-resident rhizobia effect. Further studies are needed to elucidate this effect.

Water Use Characteristics of Pulses

Residual soil water in the 120-cm soil depth, measured at spring were highest in pea and lentil stubble plots (discussed above in Table 15), despite the fact that these stubbles may trap less snow during winter months. Lentil grown on the pea stubble had the highest water use efficiency (WUE) at Swift Current in 1997, but this was not the case at Stewart Valley where there was no difference among the five stubble types (Table 28). The WUE pattern was somewhat similar to the yield patterns (Table 25) where the grain yield of lentil was the highest when grown on pea stubble. High WUE for lentil grown on pea stubble indicates factors other than soil water availability determined the yield response, likely enhanced nodulation from soil resident rhiobia. Pea had the highest WUE when grown on wheat stubble in all site-years (Table 28). This reflects a combination of two elements: the lowest amount of residual soil water in wheat stubble measured in spring (Table 15), and the highest grain yield of pea when grown on the wheat stubble (Table 25). It appeared that the pea may have also benefited from the improved micro climatic conditions associated with standing wheat stubble. The WUE of pea was the lowest when grown on its own stubble, presumably due to some disease infestation. The WUE of pea was also the lowest when grown on chickpea stubble particularly in 1998 (Table 25), due to weeds.

Table 22. Plant density of pulse crops grown on five different stubble types at Swift Current (SC) and Stewart Valley (SV), from 1997 to 1999.

Crop stubble	1997		1998		1999		Mean
	SC	SV	SC	SV	SC	SV	
	--- Laird lentil ---		---------- yellow pea ----------				
	---------- plants/m^2 ----------						
Mustard	58	54	55	60	69	64	60
Pea	64	60	52	53	67	76	62
Lentil	72	62	51	66	67	80	66
Chickpea	70	56	54	77	68	76	67
Wheat	79	66	55	74	70	73	70
Lsd (0.05)	NS	NS	NS	NS	NS	NS	NS

NS, no significant difference among the five crop stubbles at P<0.05.

Table 23. Days to maturity for pulse crops grown on five different stubble types at Swift Current (SC) and Stewart Valley (SV), from 1997 to 1999.

Crop stubble	1997		1998		1999		Mean
	SC	SV	SC	SV	SC	SV	
	--- Laird lentil ---		---------- yellow pea ----------				
	---------- days ----------						
Chickpea	88	85	90	81	103	99	91
Mustard	88	85	91	81	103	99	91
Wheat	88	85	90	81	105	99	91
Lentil	89	84	92	83	103	99	92
Pea	90	85	92	83	104	99	92
Lsd (0.05)	NS	NS	0.97	0.94	NS	NS	NS

NS, no significant difference among the five crop stubbles at P<0.05.

Table 24. Biomass at anthesis for pulse crops grown on five different stubble types at Swift Current (SC) and Stewart Valley (SV), from 1997 to 1999.

Crop stubble	1997		1998		1999		Mean
	SC	SV	SC	SV	SC	SV	
	--- Laird lentil ---		---------- yellow pea ----------				
	---------- kg ha^{-1} ----------						
Pea	429	487	425	327	653	619	490
Mustard	380	372	439	477	788	594	508
Chickpea	333	381	450	281	831	794	512
Wheat	313	349	502	489	750	734	523
Lentil	385	447	557	510	735	643	546
Lsd (0.05)	NS	NS	NS	107.1	82.1	116.9	NS

NS, no significant difference among the five crop stubbles at $P<0.05$.

Table 25. Grain yields of lentil and pea grown on five different stubble types at Swift Current (SC) and Stewart Valley (SV), from 1997 to 1999.

Crop stubble	1997		1998		1999		Mean	% over wht stubble
	SC	SV	SC	SV	SC	SV		
	--- Laird lentil ---		---------- yellow pea ----------					
	---------- kg ha^{-1} ----------							
Pea	1644	1860	1310	1555	3600	3034	2167	-10
Chickpea	1320	1522	1269	1036	3999	4131	2213	-8
Mustard	1289	1760	1373	1733	3984	3198	2223	-8
Lentil	1383	1829	1547	1450	3829	3743	2297	-5
Wheat	1231	1582	1692	1937	4050	3920	2408	0
Lsd (0.05)	203.7	NS	NS	248.8	NS	NS	NS	---

NS, no significant difference among the five crop stubbles at P<0.05.

Table 26. Grain Protein Content (%) for Pulses grown on the five different stubble types at Swift Current (SC) and Stewart Valley (SV), from 1997 to 1999.

Crop stubble	1997		1998		1999		Mean
	SC	SV	SC	SV	SC	SV	
	---- *Laird Lentil* -----		---------- *Grande yellow pea* ----------				
Pea	23	27.3	25.6	24	29.4	22.9	**25.3 a**
Lentil	22.8	27.6	22.9	23.8	28.6	22.2	**24.7 a**
Chickpea	22.9	26.2	24.3	21.4	23.8	22.2	**23.5 b**
Mustard	23	25.9	24.3	21.9	23.4	22.2	**23.4 b**
Wheat	22.7	25.5	24.3	22.3	23.3	23	**23.6 b**

Table 27. Kernel weight of yellow pea grown on five different stubble types at Swift Current (SC) and Stewart Valley (SV), from 1998 to 1999.

Crop stubble	1998		1999		Mean
	SC	SV	SC	SV	
	mg seed $^{-1}$				
Wheat	196	210	234	204	211
Pea	192	230	230	194	211
Chickpea	187	216	237	209	212
Mustard	203	216	237	204	215
Lentil	191	232	243	208	218
Lsd (0.05)	NS	8.8	6.3	NS	NS

NS, no significant difference among the five crop stubbles at P<0.05.

Table 28. Water Use Efficiency for lentil or pea grown on five different stubble types at Swift Current (SC) and Stewart Valley (SV), from 1997 to 1999.

Crop stubble	1997		1998		1999		Mean	% over wht stubble
	SC	SV	SC	SV	SC	SV		
	--- Laird lentil ---		---------- yellow pea ----------					
	kg ha^{-1} mm^{-1}							
Wheat	3.8	9.8	7.4	7.6	12.1	15.4	9.4	0
Mustard	4.7	8.3	6.0	7.2	12.4	15.2	9.0	-4
Lentil	4.9	8.1	6.4	6.0	10.5	14.2	8.3	-11
Chickpea	4.1	7.5	5.8	4.1	12.2	16.0	8.3	-11
Pea	5.2	8.0	5.5	5.8	10.5	14.4	8.2	-12
Lsd (0.05)	0.9	NS	NS	1.4	1.6	NS	NS	---

NS, no significant difference among the five crop stubbles at P<0.05.

Chapter 5. Effects of Previous Crop Type and Sequences on Grain Yield, Protein Content, and Protein Yield in Kyle Durum

A uniformly managed durum wheat (Kyle) was grown in the third year following the different crop sequences, in each of the 1998, 1999, and 2000 growing seasons at Swift Current and in 1998 and 1999 at Stewart Valley. Grain yield, protein content, and protein yield of the durum crops were determined, and the data are presented as means for the five site-years.

'Kyle' Durum Grain Yield

On average, durum wheat seeded in the pulse-pulse-durum crop sequence produced the highest grain yield (2660 kg ha^{-1}), followed by the crop sequences of pulse-canola-durum (2620 kg ha^{-1}) and mustard-pea-durum (2610 kg ha^{-1}) (Fig. 1). Durum grown in the wheat-wheat-durum sequence produced the lowest grain yield (2240 kg ha^{-1}), which was 19% lower than from the pulse-pulse-durum sequence and 9% lower than from the fallow-wheat-durum sequence. It is apparent that the previous two years of pulse crops or the pulse-oilseed, oilseed-pulse alternated crop sequences provided the durum crop with significant rotational benefits. The increased durum yields in these crop sequences can be attributed to the slow-release of symbiotic soil residual N contributed by the previous pulse crops, and increased soil moisture conserved by the shallow-rooting lentil and pea crops.

'Kyle' Durum Grain Protein Content

Grain protein content of durum was highest (>13.8%) when grown in the pulse-pulse-durum, pulse-oilseed-durum, or oilseed-pulse-durum sequences, followed by wheat-pea-durum or mustard-canola-durum (Fig.2). Grain protein was lowest (11.8%) when the durum was grown in wheat-wheat-durum or fallow-wheat-durum sequences. Grain protein levels were reduced sharply when durum was grown on 2nd-year wheat stubble, averaging a

remarkable 2.7 %-units lower than when durum was grown on lentil or pea stubbles.

'Kyle' Durum Protein Yield

Total protein yield per unit area was calculated as the product of grain yield times grain protein concentration (Fig. 3). The highest protein yields were achieved by growing durum in the pulse-pulse-durum, pulse-oilseed-durum, or oilseed-pulse-durum sequences. The crop sequences of wheat-wheat-durum, fallow-wheat-durum, or oilseed-wheat-durum produced the lowest durum protein yield.

The timing of N release from decomposing pulse crop residues in association with soil organic matter dynamics may have contributed to the observed large protein benefits for the durum crops. In the long term, the inclusion of pulse crops in the crop sequence would significantly enhance the soil's nitrogen pool or improve soil N availability for N-loving crops such as cereals. Campbell et al. (1992) have reported that after 30 years of using a wheat-lentil system, protein levels in spring wheat averaged 1.2 percentages points higher than spring wheat grown in a wheat-wheat or fallow-wheat system. Aside from the slow N release from pulse residues, other factors may have contributed to these huge rotational benefits. More detailed studies are needed to elucidate the impacts of including pulse crops in cropping systems on the changes in soil biodiversity, weed seedbank, weed spectra, and diseases.

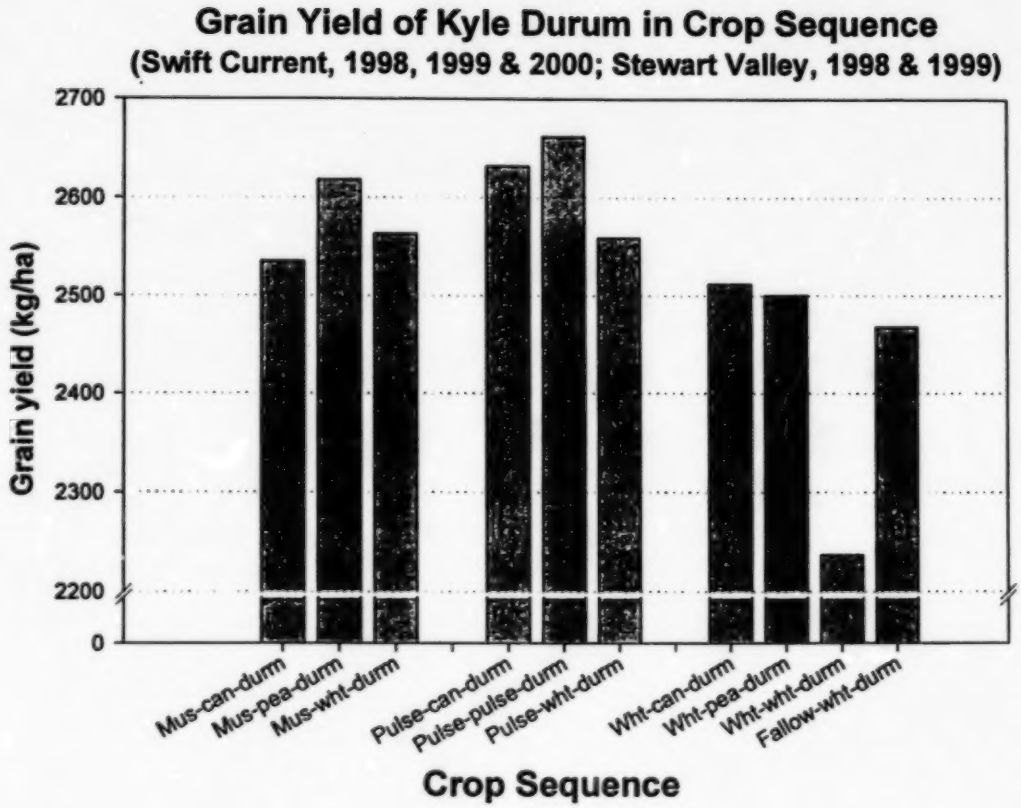

Fig. 1. Grain yield of 'Kyle' durum seeded following the different crop sequences. Each of those crop sequences was repeated in three cycles at both Swift Current and Stewart Valley. Abbreviations used in the graphs are: Mus - oriental mustard; can - argentine canola; wht - hard red spring wheat; and pulse - pea, lentil, and chickpea.

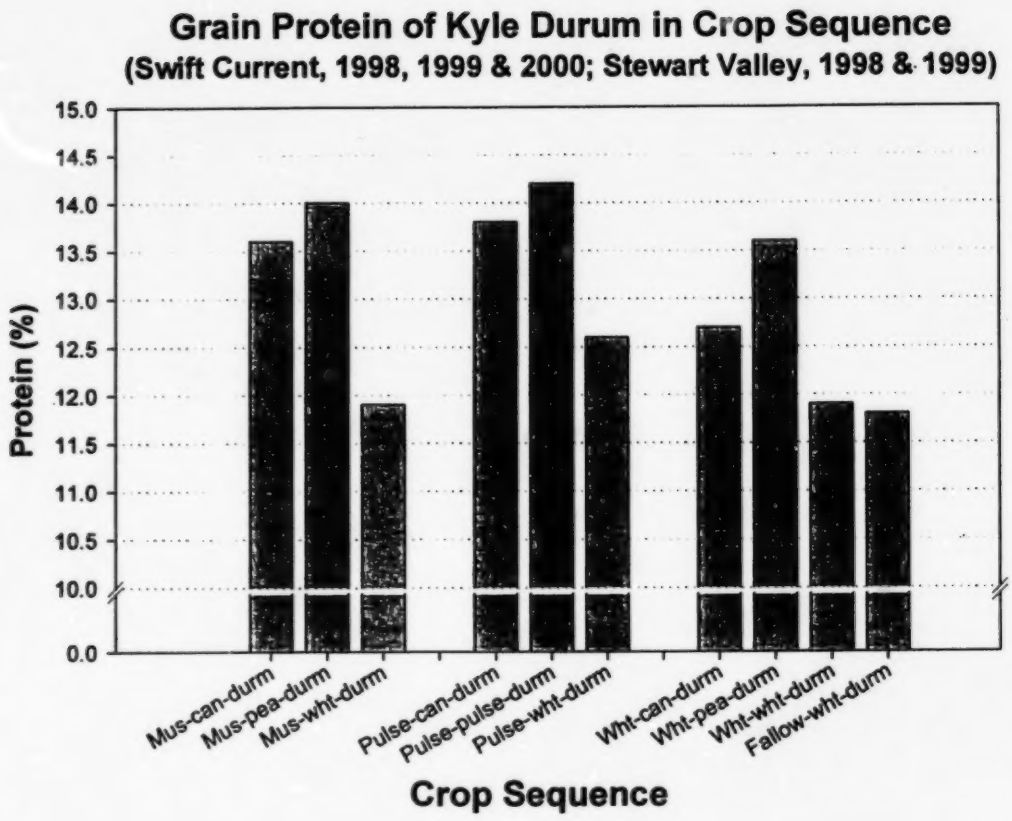

Fig. 2. Grain protein content (%) of 'Kyle' durum seeded following the different crop sequences. Each of those crop sequences was repeated in three cycles at both Swift Current and Stewart Valley. Abbreviations used in the graphs are: Mus - oriental mustard; can - argentine canola; wht - hard red spring wheat; and pulse - pea, lentil, and chickpea.

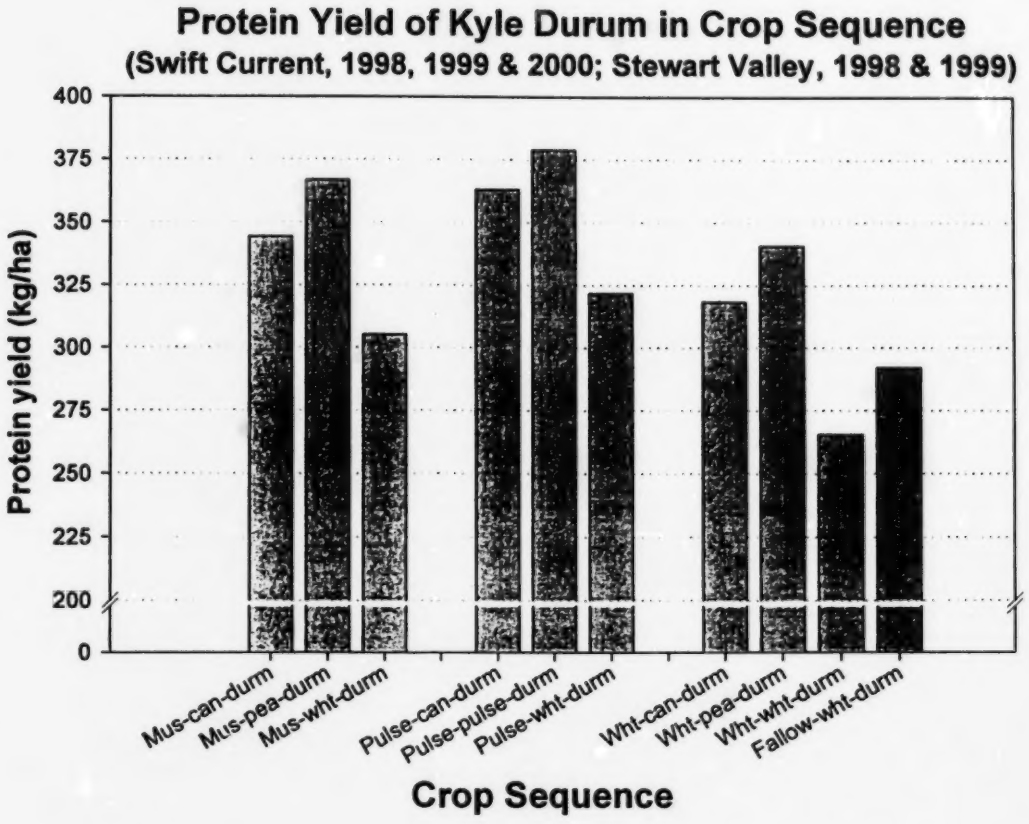

Fig. 3. Protein yield (grain yield times grain protein content) for 'Kyle' durum seeded following the different crop sequences. Each of those crop sequences was repeated in three cycles at both Swift Current and Stewart Valley. Abbreviations used in the graphs are: Mus - oriental mustard; can - argentine canola; wht - hard red spring wheat; and pulse - pea, lentil, and chickpea.

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APPENDIX:

A). Personnel

The following people have been directly involved in the project:

Title	Name	Time Spent	Salary Paid
Study leader	Yantai Gan	0.1	0.00
Former study leader	Perry Miller	0.1	0.00
Senior technician	Cal McDonald	0.2	0.00
Junior technician	Greg Ford	0.5	$29,188
General labourer	Ray Lashures	0.3	$28,792
Summer student	Holly Thomas	0.3	$2,940

B) Equipment

None

C) Project Developed Materials

Documentation of the amount and pattern of soil water conservation by pea and lentil crops has been a useful achievement in discussing strategies for extending crop rotations in the Brown soil zone. This single piece of information has generated considerable interest at several major producer meetings and scientific conferences in Western Canada. This finding may help to explain the current trend toward fallow replacement with pea and lentil.

Further, the calculation of fertilizer N equivalents among the three pulse crops has clearly demonstrated the superiority of pea in causing a rotational benefit to subsequent wheat and oilseed crops.

Study on crop sequence, crop rotation, and alternative cropping systems continue to be of

great interest to producers who are diversifying and extending wheat-based cropping systems in the Brown and Dark Brown soil zones. With the steady increases in pulse acreage in western Canada, the consideration of the effect of herbicide residue in the soil applied from the previous crops on crop selection have become a major issue. This study has addressed how to make best crop sequences based on effectively use of water and nutrient and yield potential. Further studies should be followed to address how the crop sequences would have on weed seedbank, weed spectra, soil herbicide residue, disease break, and overall soil quality. Also, more detailed research should be conducted to address the impacts of seeding pulse crops back-to-back or in a mixed fashion on yield potential, grain quality, soil biodiversity, and environmental quality in the Brown and Dark Brown soil zones.

D) Project Photos

None

E) Acknowledgement

The financial supports provided by Saskatchewan Agricultural Development Fund and Saskatchewan Pulse Growers have been acknowledged extensively through seminar presentations to various farmers meetings, annual SPARC field days, visitor's tours, various workshops, scientific conferences, and in all publications deriving from this project.

F) Expense Statement

A budget statement will be sent to you directly from SPARC finance office.